ANALYSIS REQUEST RESPONSE
TO THE CHANNEL ISLAND FOX
RECOVERY COORDINATION GROUP

DATE Sept. 10, 2004

ANALYSIS REQUEST STATEMENT

Analysis 1.3. Use the PVA models (developed in Analysis 1.1) and supporting data to determine the conditions in the wild populations that would trigger taking further foxes into captivity (e.g. during pig eradication on Santa Cruz, or if another disease outbreak occurred).

The RCG recognized that development of PVA models was an extensive effort. Because trigger points are needed in the short term due to upcoming pig eradication on Santa Cruz Island, the RCG asked the task force to conduct Analysis 1.3 prior to full development of PVA models, suggesting that initial triggers be developed based on less complex analyses or on professional judgment.

TASK FORCE LEAD

Vickie Bakker, The Nature Conservancy, Wild Population Management (WPM)
Gary Roemer, New Mexico State University, WPM

CHAIR OF EXPERTISE GROUP ASSIGNED TO TASK FORCE

Gary Roemer, New Mexico State University, WPM

TASK FORCE MEMBERS

Vickie Bakker, The Nature Conservancy, WPM
Karen Bauman, Saint Louis Zoo, Captive Population Management
Dave Garcelon, Institute for Wildlife Studies, WPM
Linda Munson, UC Davis, Fox Health
Scott Morrison, The Nature Conservancy, WPM
Stephanie Provinsky, National Park Service
Katherine Ralls, Smithsonian Institute, WPM
Hilary Swarts, UC Davis, WPM
Nancy Thomas, USGS Fox Health
Rosie Woodroffe, UC Davis, WPM
Cynthia Wilkerson, Defenders of Wildlife, WPM

EXECUTIVE SUMMARY

Island foxes on Santa Cruz Island are at risk of extinction due to golden eagle predation. The presence of feral pigs appears largely responsible for supporting breeding golden eagles in the northern Channel Islands. Land managers will attempt to eradicate feral pigs over the next two to six years, an action that could exacerbate eagle predation on foxes in the short term. The current analysis identifies trigger points for management action necessary to protect the wild Santa Cruz Island fox population in the event of increased eagle predation during pig eradication. We performed a risk assessment to identify conditions that would likely lead to unacceptable extinction risks to the wild population using Vortex (version 9.42). We used IUCN criteria for threatened status based on extinction risk and population size to guide selection of trigger points. Proposed trigger points are as follows:

Tier 1: Whenever conditions are leading to a 15% extinction risk, new efforts should be undertaken to reduce golden eagle predation (Table 2, Fig. 9).

Tier 2: Whenever conditions are leading to a 20% extinction risk, lethal control of golden eagles should be initiated (Table 2, Fig. 9).

Tier 3: Whenever the number of collared foxes drops below 50, wild foxes should be removed to captivity (Table 2, Fig. 9).

INTRODUCTION

Island foxes (*Urocyon littoralis*) on Santa Cruz Island are at risk of extinction due to golden eagle predation, a deterministic force lowering fox survival rates and population growth rates (Roemer et al. 2001a). Because island foxes have declined to extremely low levels on Santa Cruz Island, this population faces added extinction risks due to environmental and demographic stochasticity. The presence of feral pigs on Santa Cruz Island appears largely responsible for supporting breeding golden eagles in the Northern Channel Islands (Roemer et al. 2002). Since November 1999 when the first adult golden eagle was captured, a total of 38 golden eagles have been live-captured and most have been successfully translocated to distant locales (Coonan et al. in review; Coonan, pers. comm.). Despite the success of such efforts, complete removal of eagles using existing methods appears unattainable; from 10 to 14 eagles may still reside on the northern Channel Islands (B. Latta, pers. comm.). The current long-term plan for eliminating golden eagles is to eradicate feral pigs, thereby removing the primary food source for the eagles (USDI 2002, Coonan 2003). Pig eradication is likely to take from two to six years, and it is not known whether golden eagles will abandon the Channel Islands and, if they do, how long this process may take. During pig eradication, the golden eagle prey base will diminish, which could lead to added predation on island foxes and an increased extinction risk (Courchamp et al. 2003).

Although the RCG requested triggers points for increasing captive populations in the event of increased predation on foxes by golden eagles during pig eradication, the task force felt it was important to evaluate a range of options for reducing risks to wild foxes. One means of reducing the extinction risk of small wild populations is placing and breeding individuals in captivity, protected from threats and managed to optimize genetic diversity, until such threats can be reduced or eliminated (Dratch et al. 2004). In captivity, individuals can be bred for release to bolster small wild populations. Captive populations also serve as a reservoir for rebuilding a wild population in the event of an extinction. If wild populations drop to very low levels or if threats increase such that the extinction risk becomes unacceptably high, entire populations may be taken into captivity (e.g. island foxes on San Miguel and Santa Rosa Island, Coonan 2003, black-footed ferrets, Miller et al. 1996). Captive populations, however, face extinction risks from catastrophes, including disease and fire, and from demographic stochasticity. Further, if the genetic diversity is low, inbreeding depression may result or a reduction in mating opportunities may occur. In addition, behavioral changes while in captivity may reduce the fitness of captives released into the wild (Breitenmoser et al. 2001). Thus, removing all wild individuals to captivity replaces one set of risks with another. Maintaining or increasing captive breeding stocks is particularly appropriate if threat reduction requires an extended period of time during which the wild population is likely to remain at high risk.

A second approach is to reduce known threats directly and rapidly while wild populations remain at large. Lethal removal of remaining golden eagles has been advocated as a more rapid and effective means of reducing eagle predation than methods currently employed (Courchamp et al. 2003; IUCN 2003, Roemer et al. 2004; Golden eagle task force 2004). Alternative proposals for managing golden eagle predation on foxes during eradication have also been suggested, including harassing eagles or providing supplemental food (IUCN 2003; Golden eagle task force 2004). Direct threat reduction is appropriate if wild stocks face high extinction risks and threat reduction can occur before populations drop to unacceptably low levels.

The current analysis identifies trigger points for management action necessary to protect the wild Santa Cruz Island fox population in the event of increased eagle predation. Our objective was to perform a risk assessment to identify conditions that would likely lead to unacceptable extinction risks to the wild population. Because we assumed that maintenance of a wild population was a management goal, we first identified conditions that should trigger actions to reduce or eliminate eagle predation on wild foxes while maintaining a viable wild population. We took a hierarchical approach whereby the intensity of the action corresponded to the degree of extinction risk the wild fox population faced. Finally, we identified a captivity trigger at a point where the extinction of risk of the wild population increased to an unacceptable level in spite of efforts taken to reduce eagle predation.

Because the analysis request statement specifically focused on Santa Cruz Island, we focused exclusively on the potential effects of heightened eagle predation on Santa Cruz Island's wild population and did not explicitly consider other islands, the risks of catastrophe, the role of captive populations, the long-term genetic health of wild and captive populations, and the risks associated with potential interventions. We assumed that more comprehensive analyses would be conducted in the near future that would take into account these factors and that would be applicable to additional islands.

ANALYSIS

Methods

We used Vortex (version 9.42, Miller and Lacy 1999) to model the extinction risk associated with different population sizes and survival rates over a 50 year period. We reparameterized the basic model developed by Miller et al. (2003) for the Santa Cruz Island fox population using the best available data.

Basic model

We used the known fate analysis module in Program MARK (version 3.1, White 2003) to estimate survival rates from telemetry data collected since December 2000. Based on Akaike's Information Criterion, the best supported models were those of constant survival throughout the time period, survival varying by age (pup v. nonpup), and survival varying by year (Table 1, delta AIC ≤ 1.8 for these 3 models, delta AIC <2 indicates essentially equal statistical support among models, Cooch and White 2002). Survival varying by year and age received nearly as much statistical support (Delta AIC ≤ 3.0). Biological intuition and previous analyses (Roemer 1999, Roemer et al. 2001a) suggested that survival of pups and nonpups differ significantly. Biological years (May – April) were used for all analyses because pups are typically born in late April to early May.

We used two baseline survival rates for the 50 year simulation window. We modeled an optimistic scenario, assuming that the annual survival rate over the next 50 years would equal the most recently observed annual survival (i.e. May 2003 – April 2004), which was 83.6% for nonpups and 73.7% for pups ("higher assumed background survival rate," Table 1). We also modeled a pessimistic scenario, assuming the annual survival rate was equal to the mean survival rate since December 2000, or 78.6% for nonpups and 69.9% for pups ("lower assumed background survival rate", Table 1). Following Roemer et al. (2001), we specified a higher standard deviation for pup survival (18.2%) than adult survival (7.8%).

We used the reproductive parameters of Miller et al. (2003), which are similar to estimates derived from recent trapping data using more indirect measures (Bakker et al. in review). Specifically, 38.6% of age class 1 and 61.3% of older females up through age 9 reproduce, and 55.8% wean 1 pup, 35.6% wean 2 pups, and 8.6% wean 3 pups. Following Miller et al. (2003), we specified environmental variation in females breeding at 17%.

We assumed starting populations (N_o) of 30, 35, 40...100, distributed according to the stable age distribution, and a carrying capacity (K) of 1200. We assumed that triggers would be set in part based on the number of foxes collared and thus known to be alive. Currently, 58 foxes are collared on Santa Cruz

Table 1: Survival analyses of telemetry data collected since December 1999. Survival analyses were conducted using the known fate module in program MARK (version 3.1, White 2003). Models are ranked in order of statistical support as indicated by AICc values. Survival rates are shown only for the top 4 models. The age model (light shading) calculates the mean annual survival rate for pups and nonpups since December 2000 and was used to simulate the lower assumed background survival rate. The year*age model (dark shading) calculates the annual survival rate for pups and nonpups for each year since December 2000. The survival rates for the most recent full year of data (2003) were used to simulate the higher assumed background survival rate. To simulate increased eagle predation during the first year(s) of the 50-year simulation period, we used the lowest annual survival rate on record, that for 2001, (i.e. moderate eagle predation severity), and decreases of 10% (high eagle predation severity) and 20% (very high eagle predation severity) below the 2001 rate. All years are biological years (May – April). Use of the Kaplan Meier staggered entry design (Pollock et al. 1989) yields values equivalent to the month*year model.

Model (Survival varies with:)	Covariate value	Year	Annual survival rate	Standard Error	Lower 95% CI	Upper 95% CI	Model AICc	Delta AICc	AICc Weight	Model Likelihood	Number of parameters
--	--	all	0.777	0.037	0.696	0.841	274.33	0	0.25	1	1
age	nonpup	all	0.786	0.039	0.701	0.852	275.84	1.51	0.12	0.47	2
age	pup	all	0.699	0.125	0.420	0.882					
year	--	2000	0.792	0.185	0.297	0.972	276.11	1.78	0.10	0.41	5
year	--	2001	0.622	0.085	0.447	0.770					
year	--	2002	0.808	0.077	0.614	0.918					
year	--	2003	0.816	0.063	0.661	0.909					
year	--	2004	0.881	0.064	0.690	0.961					
year*age	nonpup	2000	0.839	0.156	0.350	0.981	277.37	3.04	0.06	0.22	6
year*age	nonpup	2001	0.631	0.085	0.455	0.777					
year*age	nonpup	2002	0.815	0.075	0.623	0.921					
year*age	nonpup	2003	0.836	0.062	0.677	0.926					
year*age	nonpup	2004	0.881	0.064	0.690	0.961					
year*age	pup	2000	0.741	0.228	0.218	0.967					
year*age	pup	2001	0.457	0.217	0.132	0.823					
year*age	pup	2002	0.704	0.171	0.322	0.923					
year*age	pup	2003	0.737	0.126	0.439	0.909					
year*age	pup	2004	0.805	0.144	0.407	0.961					
sex*age							277.60	3.27	0.05	0.19	3
year*sex							278.08	3.75	0.04	0.15	6
year*age*sex							279.34	5.01	0.02	0.08	7
month							279.53	5.20	0.02	0.07	12
month*year							344.90	70.57	0	0	60

Island, and land managers seek to collar up to 85, which is close to the maximum number of foxes expected to be on the island currently. We ran each scenario for 50 years and 500 iterations and did not incorporate catastrophes or supplementation. We defined extinction as 1 sex remaining.

Simulating eagle predation

We simulated a decrease in fox survival due to increased eagle predation in either year 1 or years 1 and 2 of the 50-year time period. Specifically, we modeled "moderate" eagle predation severity as equivalent to the lowest survival rate observed since December 2000. The lowest survival rates since December 2000 occurred from May 2001 – April 2002, during which time annual survival was 63.1% for nonpups and 45.7% for pups (Table 1). We modeled "high" eagle predation severity as a survival rate 10% below the lowest rate observed since December 2000, and "very high" eagle predation severity as 20% below the lowest rate since December 2000. Annual survival rates reverted to the two baseline rates for the remainder of the 50 year simulation period.

Matrix models

To further evaluate the demographic consequences of various survival scenarios and population sizes, we calculated deterministic growth rates and numbers of pups and nonpups alive after 1 year using a two-stage matrix model for pups and nonpups (Fig. 1). Reproduction (dashed lines, Fig. 1) was estimated as the mean litter size (1.53) time the sex ratio (0.5) times the proportion of females breeding in a given age class (38.6% of pups and 61.3% of nonpups). The starting population was assumed to be distributed among age classes according to the average age distribution for the past year, or 29% pups, 71% nonpups.

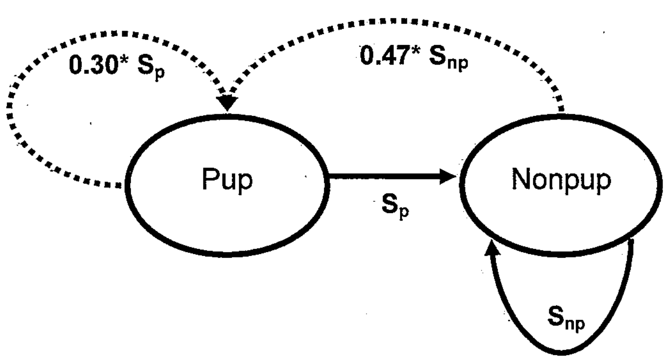

Fig. 1: Life cycle underlying the deterministic matrix model used to calculate numbers of wild foxes extant after one year under different survival scenarios and population sizes. Reproduction (dashed lines) was estimated as the mean litter size (1.53) times the sex ratio (0.5) times the proportion of females breeding in a given age class (38.6% of pups and 61.3% of nonpups). Survival rates for nonpups (S_{np}) and pups (S_p) were varied by survival scenario.

Survival rate triggers for shorter time intervals

We set triggers based on the extinction risks associated with increased eagle predation during the first year(s) of the simulation period. Eagle predation was simulated by specifying annual survival rates equal to either the lowest annual rate observed since December 2000 or to rates of 10% and 20% below the lowest annual rate. To allow managers to act proactively in response to unacceptable survival rates during shorter time intervals, we also identified trigger points associated weekly, biweekly, monthly, bimonthly, and semi-annual survival rates corresponding to annual triggers. Because survival rates typically undergo random variation throughout the year, deriving survival rates for shorter time intervals directly from annual survival rates would yield overly conservative triggers (i.e. action would be triggered too easily). Thus, we considered survival rates for the wild Santa Cruz Island fox population since December 2000 as representing the current natural temporal variation. We identified the lowest weekly, biweekly, monthly, bimonthly, and semi-annual survival rates observed since December 2000, and then calculated 10% and 20% reductions below these shorter interval rates. Thus, these shorter interval survival rate triggers are lower than interval survival rates derived from mean annual rates. Survival rates may experience non-random variation as well, but such systematic variation was not incorporated into current analyses.

Results and Discussion

There was a large difference in extinction probabilities depending on the assumed background survival rate. Under the lower assumed background survival rate scenario, which assumed future survival rates will equal the mean of the past 3.5 years, the probability of extinction appeared to stabilize at levels of about 10% for populations of 80 or more (Fig. 2, Appendix 1). At a population size of 50, the probability of extinction is from ~22% to 38%. Under the higher assumed background survival rate scenario, which assumed current high survival rates will continue, the probability of extinction is near zero for population sizes of 60 or more (Fig. 3, Appendix 1). Stochastic growth rates were less than 0 for essentially all simulations incorporating the lower assumed background survival rate (Fig. 4, Appendix 1), but exceeded 0 for the higher assumed background survival rate (Fig. 5, Appendix 1). One year of decreased survival increased the extinction risk for all scenarios, but the effect was minimal for most starting population sizes with the higher assumed background survival rate. With two years of reduced survival, however, extinction risk rises more significantly under both background survival rates (Fig. 6-7, Appendix 1). Numbers of Santa Cruz Island foxes remaining after one year exceeded 50 for the higher assumed background survival rate if the starting number of foxes exceeds 45 (Fig. 8) and for the lower assumed background survival rate if the starting number was 50. When survival rates are reduced to simulate increased eagle predation severity, 65 to 80 foxes are needed to maintain numbers greater than 50.

We suggest that caution be used in interpreting the results as the survival estimates used to simulate population trajectories and estimate the probability of population extinction have moderate standard errors and overlapping confidence intervals (Table 1). Thus, the mean annual estimates of survival used in the simulations under the two assumed background survival rates are statistically indistinguishable yet yield very different population growth rates – one negative and the other positive. Given our uncertainty about fox survival rates and the sensitivity of extinction probability estimates to these parameters, the task force relied on the more conservative lower assumed background survival rate to set triggers.

The IUCN defines threatened taxa as either vulnerable, endangered, or critically endangered (IUCN 2001). Classification criteria are based on, among other factors, extinction probability and numbers of mature individuals. If a taxon has a "quantitative analysis showing the probability of extinction in the wild is at least 10% within 100 years" or if it has a population of fewer than 10,000 mature individuals, it is assigned a status of vulnerable. Endangered taxa have a probability of extinction of at least 20% within 20 years or have populations of fewer than 250 mature individuals. Critically endangered species have a 50% extinction risk within 10 years or fewer than 50 mature individuals. An effective population size of 50 individuals is sometimes also considered a rule-of-thumb minimum to prevent inbreeding depression in the short-term (Franklin 1980, Soule 1980). Unfortunately, because the effective population size is typically about one-tenth of the census population size (Frankham 1995), the IUCN criterion for critically endangered status would generally be applied to effective populations far below 50.

According to IUCN definitions, the Santa Cruz Island fox will likely always be vulnerable (≤10,000 mature individuals). We chose the 15% extinction risk for a tier 1 action trigger. This risk level represents an increase of 50% over the 10% risk level, the point at which the population's risk is midway between the vulnerable and endangered criteria. At this point, efforts should be made to reduce eagle predation on foxes using any and all methods available. We chose the 20% extinction risk level, IUCN's risk level for endangered status, as a tier 2 action trigger. At this point, lethal control of golden eagles should be initiated. These trigger criteria assume that land managers will continue intensive survival monitoring of island foxes (Bakker 2004) to help ensure that survival analyses have adequate power to distinguish between the different survival rates that trigger action.

Finally, as a tier 3 action trigger, we chose the point at which the number of collared foxes, and thus the number of foxes known alive, drops below 50 as the lowest threshold. At this point, all foxes known to be alive would be brought into captivity. This trigger point coincides with the IUCN criterion of 50 mature individuals for critically endangerment. Island foxes cannot be collared until late summer or early fall due to weight restrictions, thus excluding young pups from the collared sample; however, some foxes that are not mature individuals would be included in this sample. This trigger point appears to coincide with the point at which extinction risk begins to rise rapidly under the simulations completed through these analyses. This trigger is clearly below an effective population size of 50 and hence will result in loss of considerable genetic variation than was originally present in the wild population. In fact, with current population sizes of 65 – 85 foxes, it is very likely that there has been a significant loss in genetic variation in the Santa Cruz fox population. It is the hope of the task force that implementation of tier 1 and tier 2 actions will prevent the population from dropping to this level.

PRESENTATION OF ALTERNATIVES

Tier 1 trigger: Attempt to reduce golden eagle predation by methods other than eagle capture and removal.

We chose the 15% extinction risk for a tier 1 action trigger. This risk level represents the point at which the population's risk is midway between the IUCN's vulnerable (10% extinction risk) and endangered categories (20% extinction risk; IUCN 2001). Whenever conditions are leading to a 15% extinction risk under the lower assumed baseline survival rate scenarios (Fig. 9, Table 2), new efforts should be undertaken to reduce golden eagle predation.

Tier 2 trigger: Attempt lethal control of golden eagles.

We chose the 20% extinction risk for a tier 2 action trigger. This risk level represents the point at which the population's status shifts to endangered by IUCN criteria (IUCN 2001). Whenever conditions are leading to a 20% extinction risk under the lower assumed baseline survival rate scenarios (Fig. 9, Table 2) lethal control of golden eagles should be initiated.

Tier 3 trigger: Remove wild foxes to captivity.

Whenever the number of collared foxes drops below 50, wild foxes should be removed to captivity (Fig. 9, Table 2). This population size qualifies the subspecies as critically endangered according to the IUCN, or "facing an extremely high risk of extinction in the wild (IUCN 2001)." This number is also clearly below an effective population size of 50, sometimes considered a rule-of-thumb minimum to prevent inbreeding depression in the short-term (Franklin 1980, Soule 1980). It also appears to coincide with the point at which extinction risk begins to rise rapidly under the simulations completed through these analyses.

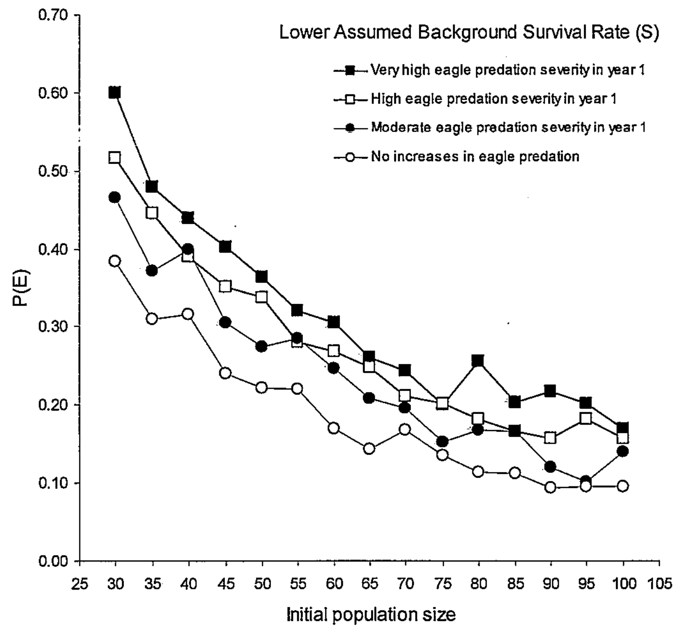

Fig. 2: Probabilities of extinction over 50 years based on simulation modeling using a variety of initial population sizes, a lower assumed background survival rate equal to the mean rate since December 2000 (Table 1), and increased eagle predation in the first year of the simulation period. See Tables 1 - 2 for definitions eagle predation severity.

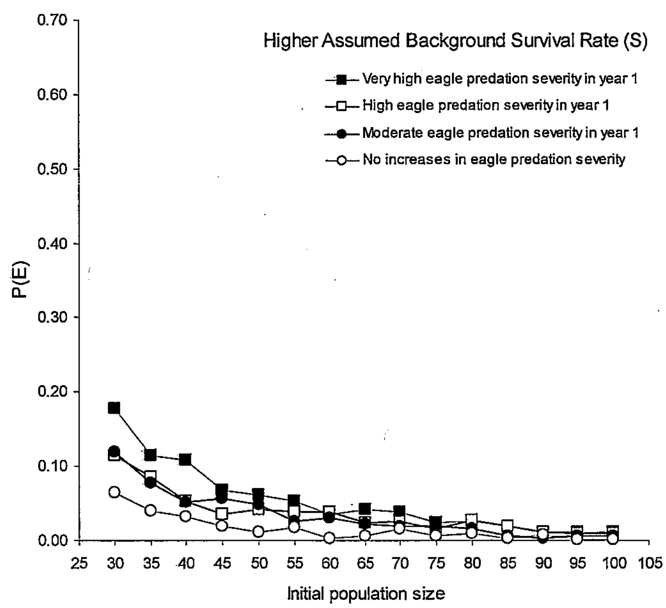

Fig. 3: Probabilities of extinction over 50 years based on simulation modeling using a variety of initial population sizes, a higher assumed background survival rate equal to the rate observed during the most recent full year on record (May 2003 – April 2004; Table 1), and increased eagle predation in the first year of the simulation period. See Tables 1 - 2 for definitions eagle predation severity.

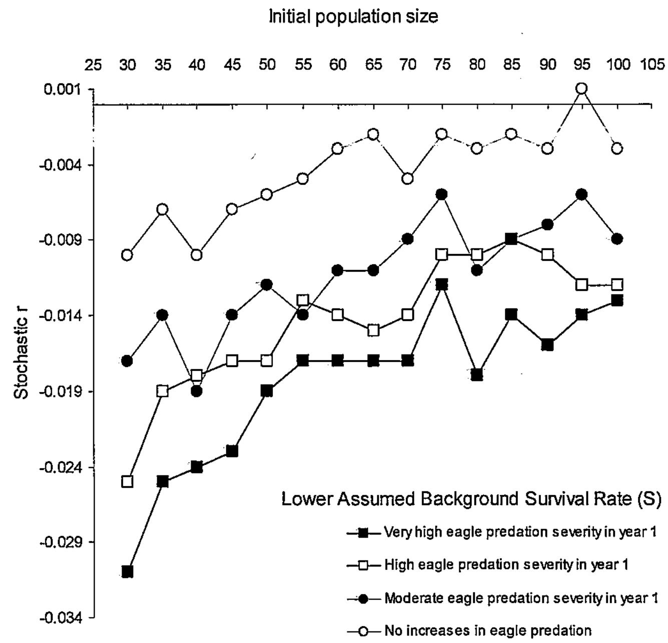

Fig 4. Stochastic r over 50 years based on simulation modeling using a variety of initial population sizes, a lower assumed background survival rate equal to the mean rate since December 2000 (Table 1), and increased eagle predation in the first year of the simulation period. See Tables 1 - 2 for definitions eagle predation severity.

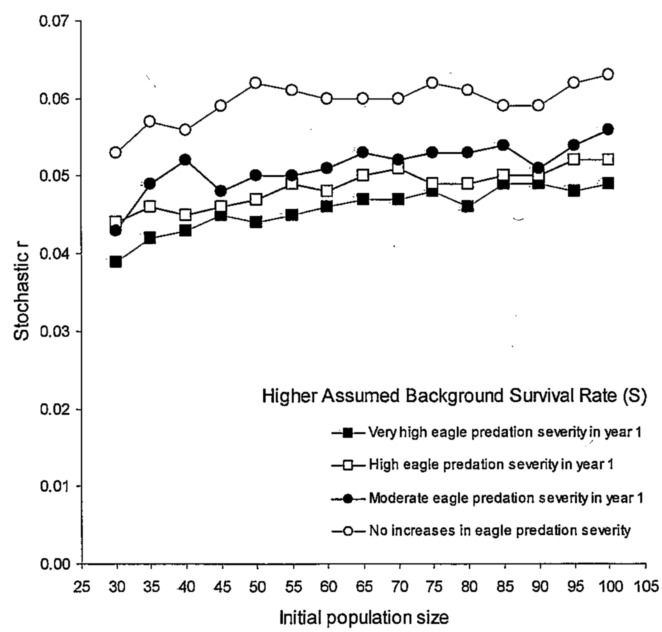

Fig. 5. Stochastic r over 50 years based on simulation modeling using a variety of initial population sizes, a higher assumed background survival rate equal to the rate observed during the most recent full year on record (May 2003 – April 2004; Table 1), and increased eagle predation in the first year of the simulation period. See Tables 1 - 2 for definitions eagle predation severity.

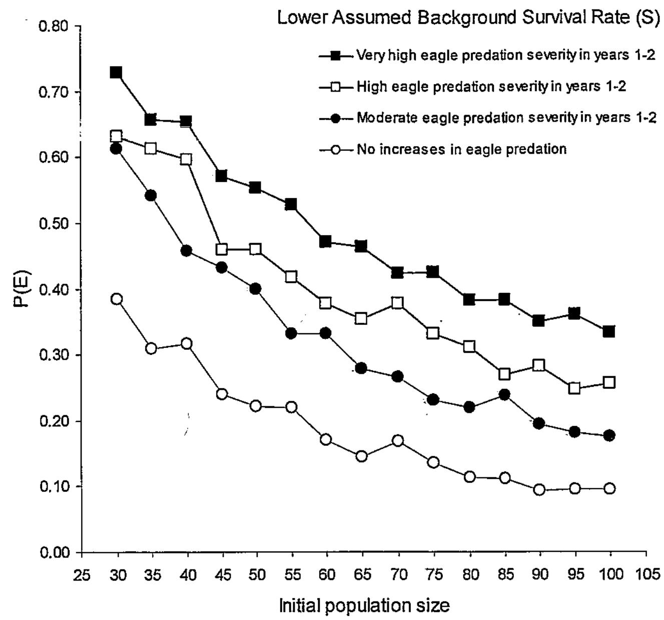

Fig. 6: Probabilities of extinction over 50 years based on simulation modeling using a variety of initial population sizes, a lower assumed background survival rate equal to the mean rate since December 2000 (Table 1), and increased eagle predation in the first 2 years of the simulation period. See Tables 1 - 2 for definitions eagle predation severity.

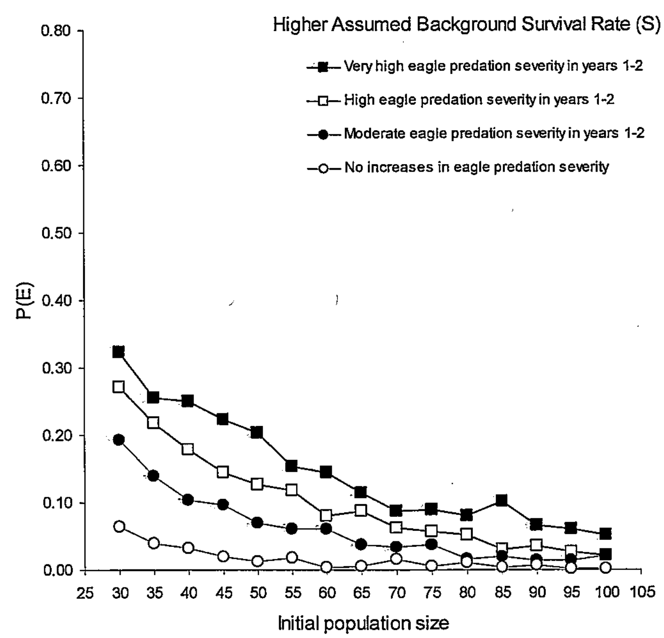

Fig. 7: Probabilities of extinction over 50 years based on simulation modeling using a variety of initial population sizes, a higher assumed background survival rate equal to the rate observed during the most recent full year on record (May 2003 – April 2004; Table 1), and increased eagle predation in the first 2 years of the simulation period. See Tables 1 - 2 for definitions eagle predation severity.

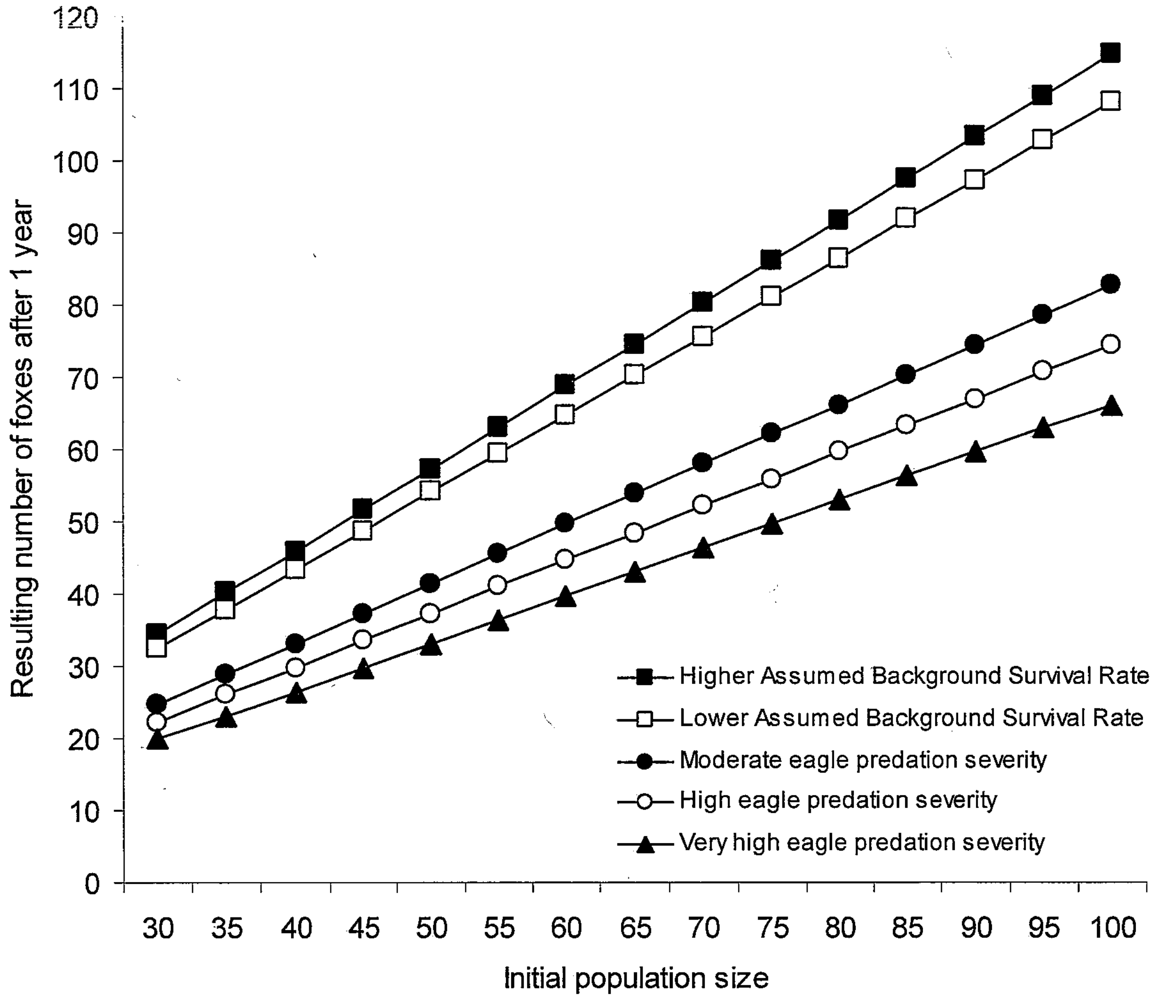

Fig. 8: Number of foxes remaining after 1 year based on a 2-stage determinstic matrix model. The lower assumed background survival rate was equal to the mean rate since December 2000 (Table 1). The higher assumed background survival rate was equal to the rate observed during the most recent full year on record (May 2003 – April 2004; Table 1). See Tables 1 - 2 for definitions eagle predation severity.

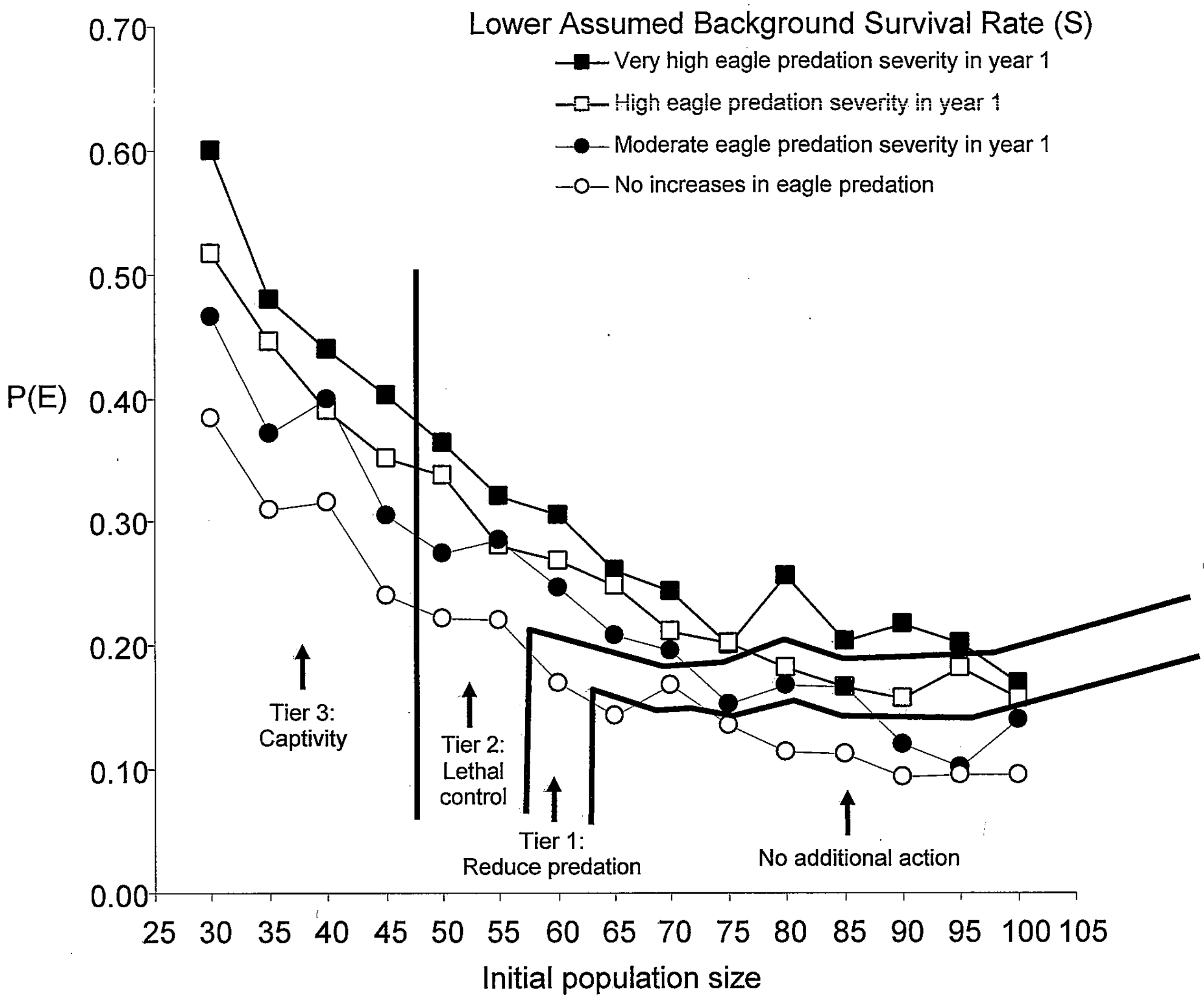

Fig. 9: Proposed management action triggers for the Santa Cruz Island fox. Probabilities of extinction are based on simulation modeling, assuming a variety of starting population sizes and a lower assumed background survival rate equal to the mean rate observed since December 2000 over a 50 year time period. Some modeled scenarios included increases in golden eagle predation in the first year of the 50-year time period. Moderate golden eagle predation severity was modeled as survival equal to the lowest rate observed since December 2000. High eagle predation severity was a survival rate 10% below the lowest rate observed, and very high predation was 20% below the lowest rate. The tier 1 trigger is an extinction risk of ≥15%, and the tier 2 trigger is an extinction risk of ≥20%. We assumed that maintaining a viable wild fox population was a key management goal, thus, both initial triggers initiate actions aimed at reducing threats to the wild population. The tier 3 trigger is <50 individuals known alive (i.e. 50 collared foxes), representing the point at which the wild population is no longer viable and should be brought into captivity.

Table 2: Summary of proposed trigger conditions. Eagle predation severity indicates the survival rate that triggers action. Moderate eagle predation severity is the survival rates for 2001, the lowest rate observed since December 2000. High eagle predation is a decrease of 10% below this rate. Very high eagle predation is a decrease of 20% below this rate. Although modeling was conducted with age-structured vital rates, triggers were calculated based on mean survival rates for nonpups and pups. Triggers intervals of less than one year were based on the lowest interval survival rate observed since December 2000 rather than on an extrapolation from the annual rate (see table notes).

Number of foxes collared	Number of mortalities in collared sample						**Eagle predation severity**	Management action		
	Weekly	Bi-weekly	Monthly	Bi-monthly	6 month	Annual		Tier 1: Reduce eagle predation	Tier 2: Lethal control of eagles	Tier 3: Wild foxes to captivity
30							any			X
35							any			X
40							any			X
45							any			X
50							any		X	
55							any		X	
60							any	X		
60	6	6	9	9	17	23	Moderate		X	
65	7	7	9	9	19	25	Moderate		X	
70	8	8	10	10	20	26	Moderate		X	
75	8	8	11	11	22	28	Moderate	X		
75	15	15	17	17	27	33	High		X	
80	9	9	11	11	23	30	Moderate	X		
80	23	23	25	25	34	40	Very high		X	
85	9	9	12	12	24	32	Moderate	X		
85	24	24	27	27	37	43	Very high		X	
90	18	18	21	21	32	40	High	X		
90	26	26	28	28	39	45	Very high		X	
95	19	19	22	22	34	42	High	X		
95	27	27	30	30	41	48	Very high		X	
100	20	20	23	23	36	44	High	X		

Notes: Numbers of mortalities in collared sample were calculated based on the following interval survival rates:

Eagle predation severity	Weekly	Bi-weekly	Monthly	Bi-monthly	6-month	Annual
			Survival rates			
Moderate	89%	89%	86%	86%	71%	62%
High	80%	80%	77%	77%	64%	56%
Very high	71%	71%	69%	69%	57%	50%

Literature cited

Bakker, V. J. 2004. Survival rate monitoring and estimation for the Santa Cruz Island Fox. Draft report submitted to The Nature Conservancy, March 9, 2004.

Bakker, V. J., D. K. Garcelon, E. T. Aschehoug, K. R. Crooks, C. Newman, G. Schmidt, D. H. Van Vuren, and R. Woodroffe. in review. Current status of the Santa Cruz Island Fox (*Urocyon littoralis santacruzae*). Proceedings of the Sixth California Islands Symposium.

Breitenmoser, U., C. Breitenmoser-Wursten, L. N. Carbyn, and S. M. Funk. 2001. Assessment of carnivore reintroductions. Pages 241-281 *in* J. L. Gittleman, S. M. Funk, D. Macdonald and R. K. Wayne, editors. Carnivore Conservation. Cambridge University Press, Cambridge, UK.

Cooch, E., and G. White. 2002. Program MARK -- analysis of data from marked individuals -- a gentle introduction, 2nd edition. Online: http://www.cnr.colostate.edu/~gwhite/mark/mark.htm.

Coonan, T. J. 2003. Recovery strategy for island foxes (*Urocyon littoralis*) on the northern Channel Islands. National Park Service, Ventura, California.

Coonan, T. J., K. Rutz, G. W. Roemer, D. K. Garcelon, B. C. Latta, M. M. Gray, and E. T. Aschehoug. Island fox recovery hindered by golden eagles on the northern Channel Islands. Proceedings of the Sixth California Islands Symposium, Santa Barbara Museum of Natural History, Santa Barbara, California. In press.

Courchamp, F., R. Woodroffe, and G. Roemer. 2003. Removing protected populations to save endangered species. Science **302**:1532-1533.

Dratch, P., T. Coonan, and D. Graber. 2004. Predators and prey in the Channel Islands - Reply to Courchamp et al. Science **305**:777.

Frankham, R. 1995. Effective population size: Adult population size ratios in wildlife - A review. Genetical Research **66**:95-107.

Franklin, I. A. 1980. Evolutionary changes in small populations. Pages 135–150 *in* M. E. Soule and B. A. Wilcox, editors. Conservation biology: an evolutionary-ecological perspective. Sinauer Associates, Sunderland, Massachusetts.

Golden eagle task force. 2004. Intervention options in the event of trigger points being reached, Analysis X.X, submitted to RCG August 10, 2004.

IUCN. 2001. IUCN Red List Categories and Criteria (version 3.1). IUCN Species Survival Commission, Gland, Switzerland.

IUCN/Species Survival Commission. 2003. "CSG scientists call for urgent action to save the endangered island fox" press release 27 November 2003 (available at www.canids.org/bulletins/island_fox.htm).

Miller, B., R. P. Reading, and S. Forrest. 1996. Prairie night: Black-footed ferrets and the recovery of endangered species. Smithsonian Institution Press, Washington, DC.

Miller, P. S., and R. C. Lacy. 1999. VORTEX: A stochastic simulation of the extinction process. Version 8 user's manual. Conservation Breeding Specialists Group (SSC/IUCN). Apple Valley, MN.

Miller, P. S., G. W. Roemer, J. Laake, C. Wilcox, and T. J. Coonan. 2003. Population viability assessment for selected Channel Island fox wild populations, Appendix B. Pages 60-81 *in* T. J. Coonan, editor. Recovery Strategy for Island foxes (*Urocyon littoralis*) on the northern Channel Islands. National Park Service, Channel Islands National Park, Ventura, California.

Pollock, K., S. R. Winterstein, C. M. Bunck, and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management **53**:7-15.

Roemer, G. W. 1999. The ecology and conservation of the island fox (*Urocyon littoralis*). Ph.D. dissertation. University of California, Los Angeles.

Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001a. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. Animal Conservation **4**:307-318.

Roemer, G. W., C. J. Donlan, and F. Courchamp. 2002. Golden eagles, feral pigs, and insular carnivores: How exotic species turn native predators into prey. Proceedings of the National Academy of Science **99**:791-796.

Roemer, G. W., P. S. Miller, J. Laake, C. Wilcox, and T. J. Coonan. 2001b. Draft island fox demographic workshop report. Unpublished manuscript on file at park headquarters. Channel Island National Park, Ventura, California.

Roemer, G. W., R. Woodroffe, and F. Courchamp. 2004. Predators and prey in the Channel Islands - Response to Dratch et al. and Helgen. Science **305**:778.

Soule, M. E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. Pages 151–169 *in* M. Soule, E. and B. A. Wilcox, editors. Conservation biology: an evolutionary-ecological perspective. Sinauer Associates, Sunderland, Massachusetts.

U.S. Department of the Interior. 2002. Santa Cruz Island primary restoration plan. Final environmental impact statement. National Park Service, Channel Islands National Park, Ventura, California.

Appendix 1: Vortex output

Starting population size (No)	Years of increased eagle predation	Eagle predation severity	Stochastic r	SD(r)	P(E)	N-extant	SD (Next)
			Higher assumed baseline survival rate				
30	none	no increase	0.053	0.216	0.064	614.66	424.36
35	none	no increase	0.057	0.214	0.04	673.85	424.37
40	none	no increase	0.056	0.211	0.032	692.78	417.72
45	none	no increase	0.059	0.209	0.02	761.4	405.92
50	none	no increase	0.062	0.207	0.012	798.28	400.62
55	none	no increase	0.061	0.207	0.018	808.11	392.47
60	none	no increase	0.06	0.206	0.004	804.05	379.35
65	none	no increase	0.06	0.206	0.006	812.89	378.08
70	none	no increase	0.06	0.207	0.016	844.04	384.64
75	none	no increase	0.062	0.203	0.006	869.51	354.71
80	none	no increase	0.061	0.204	0.01	853.3	371.78
85	none	no increase	0.059	0.204	0.004	844.93	364.44
90	none	no increase	0.059	0.205	0.008	859.09	361.5
95	none	no increase	0.062	0.202	0.002	909.87	339.21
100	none	no increase	0.063	0.202	0.002	917.35	328.15
30	1	moderate	0.043	0.235	0.12	528.58	419.83
35	1	moderate	0.049	0.228	0.078	604.56	426.98
40	1	moderate	0.052	0.225	0.052	637.04	417.49
45	1	moderate	0.048	0.225	0.056	646.47	433.45
50	1	moderate	0.05	0.226	0.048	716.54	417.71
55	1	moderate	0.05	0.223	0.026	690.91	414.18
60	1	moderate	0.051	0.222	0.03	743.24	405.93
65	1	moderate	0.053	0.222	0.022	761.25	411.29
70	1	moderate	0.052	0.218	0.02	768.93	398.61
75	1	moderate	0.053	0.219	0.02	791.49	395.72
80	1	moderate	0.053	0.218	0.016	806.34	383.72
85	1	moderate	0.054	0.216	0.006	818.75	393.96
90	1	moderate	0.051	0.217	0.004	797.74	386.26
95	1	moderate	0.054	0.215	0.006	838.78	368.86
100	1	moderate	0.056	0.217	0.006	859.76	356.39
30	1	high	0.044	0.238	0.114	530.29	425.7
35	1	high	0.046	0.235	0.086	567.82	407.21
40	1	high	0.045	0.241	0.054	653.04	420.51
45	1	high	0.046	0.237	0.036	670.54	426.07
50	1	high	0.047	0.236	0.042	702.83	422.4
55	1	high	0.049	0.23	0.038	688.78	420.64
60	1	high	0.048	0.229	0.038	717.27	424
65	1	high	0.05	0.226	0.024	732.36	415.17
70	1	high	0.051	0.226	0.026	778.44	404.14
75	1	high	0.049	0.225	0.016	734.43	421.86
80	1	high	0.049	0.225	0.028	777.96	396.02
85	1	high	0.05	0.226	0.02	787.13	399.05
90	1	high	0.05	0.225	0.012	772.55	388.43

Starting population size (No)	Years of increased eagle predation	Eagle predation severity	Stochastic r	SD(r)	P(E)	N-extant	SD (Next)
95	1	high	0.052	0.221	0.01	806.56	385.94
100	1	high	0.052	0.223	0.01	820.01	383.05
30	1	very high	0.039	0.254	0.178	528.29	424.44
35	1	very high	0.042	0.247	0.114	563.47	436.48
40	1	very high	0.043	0.246	0.108	602.16	417.76
45	1	very high	0.045	0.242	0.068	612.9	431.01
50	1	very high	0.044	0.241	0.062	626.1	422.65
55	1	very high	0.045	0.241	0.054	653.04	420.51
60	1	very high	0.046	0.237	0.036	670.54	426.07
65	1	very high	0.047	0.236	0.042	702.83	422.4
70	1	very high	0.047	0.235	0.038	727.59	410.28
75	1	very high	0.048	0.233	0.024	749.77	405.69
80	1	very high	0.046	0.233	0.026	747.84	394.49
85	1	very high	0.049	0.233	0.02	778.91	398.13
90	1	very high	0.049	0.233	0.012	769.71	395.94
95	1	very high	0.048	0.234	0.012	777.6	384.81
100	1	very high	0.049	0.232	0.012	798.95	384.98
30	1 and 2	moderate	0.038	0.238	0.192	532.68	433.34
35	1 and 2	moderate	0.04	0.239	0.14	544.96	415.4
40	1 and 2	moderate	0.042	0.233	0.104	566.86	410.32
45	1 and 2	moderate	0.041	0.231	0.096	616.75	426.85
50	1 and 2	moderate	0.044	0.23	0.07	638.19	431.48
55	1 and 2	moderate	0.041	0.23	0.06	619.64	433.21
60	1 and 2	moderate	0.044	0.228	0.06	666.2	427.83
65	1 and 2	moderate	0.046	0.223	0.038	696.9	415.02
70	1 and 2	moderate	0.045	0.225	0.034	701.92	412.7
75	1 and 2	moderate	0.045	0.225	0.038	731.22	418.82
80	1 and 2	moderate	0.049	0.221	0.016	757.66	396.16
85	1 and 2	moderate	0.046	0.223	0.02	740.87	406.04
90	1 and 2	moderate	0.046	0.22	0.014	769.1	412.84
95	1 and 2	moderate	0.046	0.221	0.014	764.65	418.59
100	1 and 2	moderate	0.045	0.222	0.022	770.83	407.87
30	1 and 2	high	0.03	0.256	0.272	493.62	417.61
35	1 and 2	high	0.034	0.252	0.218	531.52	433.96
40	1 and 2	high	0.031	0.25	0.178	507.93	425.73
45	1 and 2	high	0.035	0.247	0.144	549.9	425.02
50	1 and 2	high	0.033	0.244	0.126	560.65	425.31
55	1 and 2	high	0.036	0.242	0.118	585.65	423.21
60	1 and 2	high	0.037	0.239	0.08	601.72	409.54
65	1 and 2	high	0.039	0.239	0.088	678.96	416.99
70	1 and 2	high	0.038	0.238	0.062	635.41	425.77
75	1 and 2	high	0.04	0.238	0.058	684.69	430.35
80	1 and 2	high	0.04	0.235	0.052	679.55	416.81
85	1 and 2	high	0.041	0.233	0.03	713.29	400.58
90	1 and 2	high	0.04	0.234	0.036	685.96	412.87
95	1 and 2	high	0.041	0.234	0.026	699.85	415.38
100	1 and 2	high	0.043	0.231	0.022	745.23	409.81
30	1 and 2	very high	0.02	0.264	0.324	404.66	388.66

Starting population size (No)	Years of increased eagle predation	Eagle predation severity	Stochastic r	SD(r)	P(E)	N-extant	SD (Next)
35	1 and 2	very high	0.026	0.258	0.256	454.31	401.91
40	1 and 2	very high	0.023	0.257	0.25	455.67	404.72
45	1 and 2	very high	0.027	0.263	0.224	532.57	409.37
50	1 and 2	very high	0.027	0.262	0.204	542.08	418.04
55	1 and 2	very high	0.028	0.258	0.154	531.19	425.61
60	1 and 2	very high	0.03	0.257	0.144	564.02	413.13
65	1 and 2	very high	0.031	0.255	0.114	559.17	416.47
70	1 and 2	very high	0.034	0.251	0.088	624.49	432.26
75	1 and 2	very high	0.031	0.252	0.09	601.9	425.45
80	1 and 2	very high	0.033	0.252	0.08	631.77	414.24
85	1 and 2	very high	0.032	0.252	0.102	667.37	432.2
90	1 and 2	very high	0.032	0.249	0.066	633.73	428.83
95	1 and 2	very high	0.034	0.249	0.06	660.44	419.28
100	1 and 2	very high	0.034	0.25	0.052	679.24	423.55
		Lower assumed baseline survival rate					
30	none	no increase	-0.01	0.235	0.384	102.21	128.67
35	none	no increase	-0.007	0.228	0.31	135.75	204.39
40	none	no increase	-0.01	0.229	0.316	135	206.09
45	none	no increase	-0.007	0.224	0.24	131.96	191.88
50	none	no increase	-0.006	0.222	0.222	140.77	180.14
55	none	no increase	-0.005	0.219	0.22	168.46	213.45
60	none	no increase	-0.003	0.218	0.17	177.81	227.51
65	none	no increase	-0.002	0.216	0.144	190.94	247.13
70	none	no increase	-0.005	0.215	0.168	188.01	233.91
75	none	no increase	-0.002	0.213	0.136	210.97	259.71
80	none	no increase	-0.003	0.211	0.114	194.69	224.79
85	none	no increase	-0.002	0.212	0.112	217.28	256.75
90	none	no increase	-0.003	0.211	0.094	223.19	278.3
95	none	no increase	0.001	0.209	0.096	264.83	294.3
100	none	no increase	-0.003	0.211	0.096	226.58	258.82
30	1	moderate	-0.017	0.251	0.466	102.27	140.47
35	1	moderate	-0.014	0.245	0.372	119.17	190.59
40	1	moderate	-0.019	0.244	0.4	110.29	151.61
45	1	moderate	-0.014	0.24	0.306	113.27	169.56
50	1	moderate	-0.012	0.235	0.274	140.51	200.37
55	1	moderate	-0.014	0.236	0.286	143.83	204.27
60	1	moderate	-0.011	0.233	0.246	157.33	216.53
65	1	moderate	-0.011	0.228	0.208	142.77	191.33
70	1	moderate	-0.009	0.226	0.196	177.86	237.11
75	1	moderate	-0.006	0.224	0.152	183.01	238.22
80	1	moderate	-0.011	0.227	0.168	176.28	252.4
85	1	moderate	-0.009	0.225	0.166	191.53	243.33
90	1	moderate	-0.008	0.222	0.12	182.81	232.45
95	1	moderate	-0.006	0.22	0.102	212.61	270.69
100	1	moderate	-0.009	0.221	0.14	200.68	249.28
30	1	high	-0.025	0.262	0.516	87.51	132.28

Starting population size (No)	Years of increased eagle predation	Eagle predation severity	Stochastic r	SD(r)	P(E)	N-extant	SD (Next)
35	1	high	-0.019	0.252	0.446	104.86	149.6
40	1	high	-0.018	0.253	0.39	112.01	169.2
45	1	high	-0.017	0.246	0.352	117.59	171.23
50	1	high	-0.017	0.244	0.338	124.81	176.99
55	1	high	-0.013	0.241	0.28	156.16	223.12
60	1	high	-0.014	0.239	0.268	137.52	180.45
65	1	high	-0.015	0.239	0.248	152.08	216.74
70	1	high	-0.014	0.236	0.212	139.73	200.64
75	1	high	-0.01	0.233	0.202	175.97	228.35
80	1	high	-0.01	0.233	0.182	171.46	220.47
85	1	high	-0.009	0.23	0.166	181.98	236.97
90	1	high	-0.01	0.231	0.158	189.57	236.54
95	1	high	-0.012	0.232	0.182	191.7	250.85
100	1	high	-0.012	0.229	0.158	187.15	239.94
30	1	very high	-0.031	0.278	0.6	91.19	133.14
35	1	very high	-0.025	0.271	0.48	86.08	130.03
40	1	very high	-0.024	0.266	0.44	108.09	183.4
45	1	very high	-0.023	0.259	0.402	112.1	182.86
50	1	very high	-0.019	0.253	0.364	126.3	193.62
55	1	very high	-0.017	0.251	0.32	135.82	195.04
60	1	very high	-0.017	0.251	0.306	144.32	206.43
65	1	very high	-0.017	0.248	0.26	135.01	195.86
70	1	very high	-0.017	0.246	0.244	140.57	201.26
75	1	very high	-0.012	0.243	0.2	160.29	212.43
80	1	very high	-0.018	0.244	0.256	167.35	235.08
85	1	very high	-0.014	0.241	0.204	165.7	218.67
90	1	very high	-0.016	0.243	0.218	186.15	249.56
95	1	very high	-0.014	0.239	0.202	182.78	229.42
100	1	very high	-0.013	0.239	0.17	183.85	236.49
30	1 and 2	moderate	-0.033	0.262	0.614	83.96	104.59
35	1 and 2	moderate	-0.031	0.26	0.542	94.77	169.36
40	1 and 2	moderate	-0.023	0.251	0.458	110.24	166.18
45	1 and 2	moderate	-0.023	0.247	0.432	112.17	164.21
50	1 and 2	moderate	-0.023	0.244	0.4	117.61	165.03
55	1 and 2	moderate	-0.018	0.24	0.332	126.76	177.49
60	1 and 2	moderate	-0.021	0.241	0.332	126.47	180.31
65	1 and 2	moderate	-0.018	0.236	0.278	131.89	190.31
70	1 and 2	moderate	-0.021	0.236	0.266	116.09	172.02
75	1 and 2	moderate	-0.016	0.235	0.23	154.59	220.12
80	1 and 2	moderate	-0.013	0.232	0.22	175.56	215.73
85	1 and 2	moderate	-0.016	0.229	0.238	174.83	233.25
90	1 and 2	moderate	-0.016	0.231	0.194	163.57	221.64
95	1 and 2	moderate	-0.019	0.231	0.182	147.3	214.47
100	1 and 2	moderate	-0.016	0.229	0.176	183.03	247
30	1 and 2	high	-0.038	0.277	0.632	85.93	143.35
35	1 and 2	high	-0.039	0.274	0.614	83.08	137.89
40	1 and 2	high	-0.039	0.273	0.596	101.47	161.63
45	1 and 2	high	-0.027	0.258	0.46	118.69	185.89

Starting population size (No)	Years of increased eagle predation	Eagle predation severity	Stochastic r	SD(r)	P(E)	N-extant	SD (Next)
50	1 and 2	high	-0.03	0.26	0.46	114.72	171.42
55	1 and 2	high	-0.026	0.252	0.418	118.81	164.43
60	1 and 2	high	-0.026	0.255	0.378	115.53	167.46
65	1 and 2	high	-0.026	0.249	0.354	113.6	168.91
70	1 and 2	high	-0.028	0.252	0.378	131.01	172.2
75	1 and 2	high	-0.025	0.248	0.332	138.05	212.9
80	1 and 2	high	-0.024	0.247	0.312	152.26	206.57
85	1 and 2	high	-0.022	0.243	0.27	144.16	194.17
90	1 and 2	high	-0.023	0.241	0.282	150.13	217.48
95	1 and 2	high	-0.022	0.239	0.248	147.13	204.52
100	1 and 2	high	-0.022	0.24	0.256	160.32	213.93
30	1 and 2	very high	-0.053	0.306	0.728	77.61	107.07
35	1 and 2	very high	-0.048	0.301	0.658	67.76	96.04
40	1 and 2	very high	-0.046	0.29	0.654	93.64	121.24
45	1 and 2	very high	-0.041	0.285	0.572	91	151.77
50	1 and 2	very high	-0.041	0.282	0.552	102.4	173.35
55	1 and 2	very high	-0.04	0.28	0.528	104.14	166.9
60	1 and 2	very high	-0.036	0.272	0.47	116.41	183.86
65	1 and 2	very high	-0.038	0.273	0.464	103.87	148.35
70	1 and 2	very high	-0.036	0.267	0.422	108.26	170.7
75	1 and 2	very high	-0.036	0.267	0.424	118.92	173.69
80	1 and 2	very high	-0.034	0.267	0.382	105.85	148.4
85	1 and 2	very high	-0.033	0.262	0.382	127.75	184.5
90	1 and 2	very high	-0.034	0.261	0.35	109.8	148.03
95	1 and 2	very high	-0.034	0.262	0.36	148.22	213.13
100	1 and 2	very high	-0.029	0.259	0.334	164.08	230.65